Aspect of Geochemical and Water Quality Studies of Parts of Southern Bida Basin, Southwestern, Nigeria

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Abstract

This study aims at assessing geochemical characteristics and water quality status of water samples from parts of Southern Bida basin in order to identify the physicochemical characteristics, hydrochemical facies, and geochemical signatures of the water sources through analyses and in-depth discussion of eighty-three (83) groundwater samples. pH, electrical conductivity, total dissolved solids, sodium, potassium, chloride, and bicarbonate, had average values of 6.2, 344.8 µS/cm, 179.6mg/l, 31.2mg/l, 30mg/l, 44mg/l, and 84.8mg/l, respectively. Rock-water interaction is the main determinant of groundwater chemistry, and $CaHCO_3$ is the dominant groundwater facies. Indicating the dominance of alkalis over alkaline earth elements, the chloro-alkaline indices show that 90% of the samples are undergoing reverse cation exchange reactions. Geochemical modeling using saturation index revealed that groundwater is under-saturated in comparison to the surrounding system. Total dissolved solids (TDS) measured in the samples have positive correlation coefficients of 0.66, 0.63, 0.73, and 0.85 with Na, K, SO_4, and Cl respectively. This suggests that these major ions are the major sources of TDS. Three factors were identified through factor analysis: A, B, and C which account for 41%, 20% and 9% of the total variance respectively. A comparison of the ion concentrations with globally accepted recommended values revealed that 90% of the parameters were generally within acceptable ranges and thus suitable for drinking except restricted elevation of chloride while 85% of the groundwater sample fell within the suitability range of the irrigation suitability charts.

Keywords: *Groundwater, Hydrochemical, Factor Analysis, Water Quality, Physicochemical.*

INTRODUCTION

The quality of water, one of the essential elements of the physical environment, has a significant impact on people's health, wealth, and lifespan. Access to clean water, dietary intake, labour productivity, and economic growth are all clearly correlated (Ige *et al.,* 2021). Over 80% of the 3 million people who died because of contaminated water and food in 1995 were children under the age of five. According to the World Health Organization (WHO), 2.2 million people worldwide pass away from diarrheal illnesses each year (WHO, 2019).

Water is necessary, and the development of civilization and industry depends on its availability. Up till every home has access to clean, pure, and safe water, efforts should be focused on providing potable water (Jiang *et al.,* 2016, Akhtar *et al.,* 2017, Ige *et al.,* 2020). In recent years, it has become crucial to assess the water quality that humans drink and compare it to global standards (Wang *et al.,* 2015, Ige *et al.,* 2017). A vital step in the development of agricultural and industrial projects is the evaluation of water quality (Qishlaqi *et al.,* 2017). It is impossible to overstate the value of evaluating the quality of the water. It can aid in monitoring water contamination and preventing severe environmental risks that could be brought on by it (Akoteyon, 2013; Ige *et al*., 2017 and Oloruntola *et al*., 2018).

The solutes and gases dissolved in the water, as well as the debris suspended in and floating on the water, all affect the quality of the water. It is a result of the chemical, physical and natural makeup of water as well as any changes that might have happened because of human activity. Natural water's chemical makeup can change through time and place as it travels through lithologies with various properties. Transitions between extremes of quality and quantity are also seen (Al-Ruwaih and Shafiullah, 2017).

The hydrochemical processes provide insight into the effects of anthropogenic impacts and rock-water interaction on the quality of groundwater. The seasonal and geographic variations in groundwater chemistry are caused by these geochemical processes (Ren *et al*., 2020). By interacting with aquifer minerals or by mixing with other groundwater through subterranean flow channels, groundwater undergoes chemical evolution. According to De Costa *et al.* (2019), microtopographic restrictions on spatially varied recharge were what led to an increase in solute concentrations in groundwater.

In addition, cations and silica are being added to the system through the weathering of both primary and secondary minerals. (Adithya *et al*., 2019). The supply of fresh water, a global issue that affects everyone is a major item in the sustainable development targets (SDGs). The kinds and quantities of solutes/gases dissolved in a water body determine its appropriateness for the intended uses (Ige *et al.,* 2017). Nigeria's growing population, urbanization, and subsequent contamination of water supplies brought studies into the quality of groundwater to the forefront (Ehinola, 2002; Karamouz et al., 2011). There is a dearth of data on water quality in the southern Bida basin, although several studies on the subject have been carried out in the northern and central regions of the basin. Sidi *et al*. (2016) evaluated the chemical quality of water from shallow alluvial aquifers in and around Badeggi, Central Bida basin, Nigeria. The results show that most major ionic concentrations are within drinking water limits established by the World Health Organization and Nigerian Standard for drinking water quality, except for phosphate, nitrate, and sulphate, which were above, indicating anthropogenic contribution from agricultural practices in the area. $CaHCO_3$ and $NaHCO_3$ were the recognized hydrochemical facies. It was determined that the water quality in Badeggi and its surroundings has not been negatively impacted by anthropogenic factors, but continued monitoring was advised.

Consequently, due to water pollution problems and importance of water quality to economic growth, this study will focus on assessing the geochemical and water quality appraisal in the study location.

Study Area

The southern Bida basin is located between latitudes N07°45’ and N08°30’; longitudes E006°40’ and E006°55’ (Figure 1). It covers an area of approximately 2740 km^2 and falls within Kogi and Lokoja Local Government Areas of Kogi State. Twenty-two localities within the area were studied which include Felele, Jamata, Igashe, Apamoba, Akpogu, Edeha, Karara, Bassa, Lokoja, Agbaja, Igbonla, Gegu-beki, Gegu-egba, Koton-Karfi, Banda, Bakomba, Achabo, Ozi, Ahoko, Okumi, Idori and Ohono.

The region is also made up of the river Niger, its flood plain, and its tributaries, and is distinguished by a belt of plains and mesas. The river begins in Guinea's Foutha-Djallon Mountains and travels 3,500 km to Lokoja, Kogi State, where it converges with the river Benue before continuing to the Niger Delta. It leaves behind deep, highly petroliferous strata of marine sediments along the delta front. A spring-fed creek called Patti empties into the river Niger. Since these sources of water are seasonal, they evaporate at the height of the dry season because of both a drop in the water table and evaporation. A lot of tributaries join the main river in a tree-like configuration, and this is the typical drainage pattern.

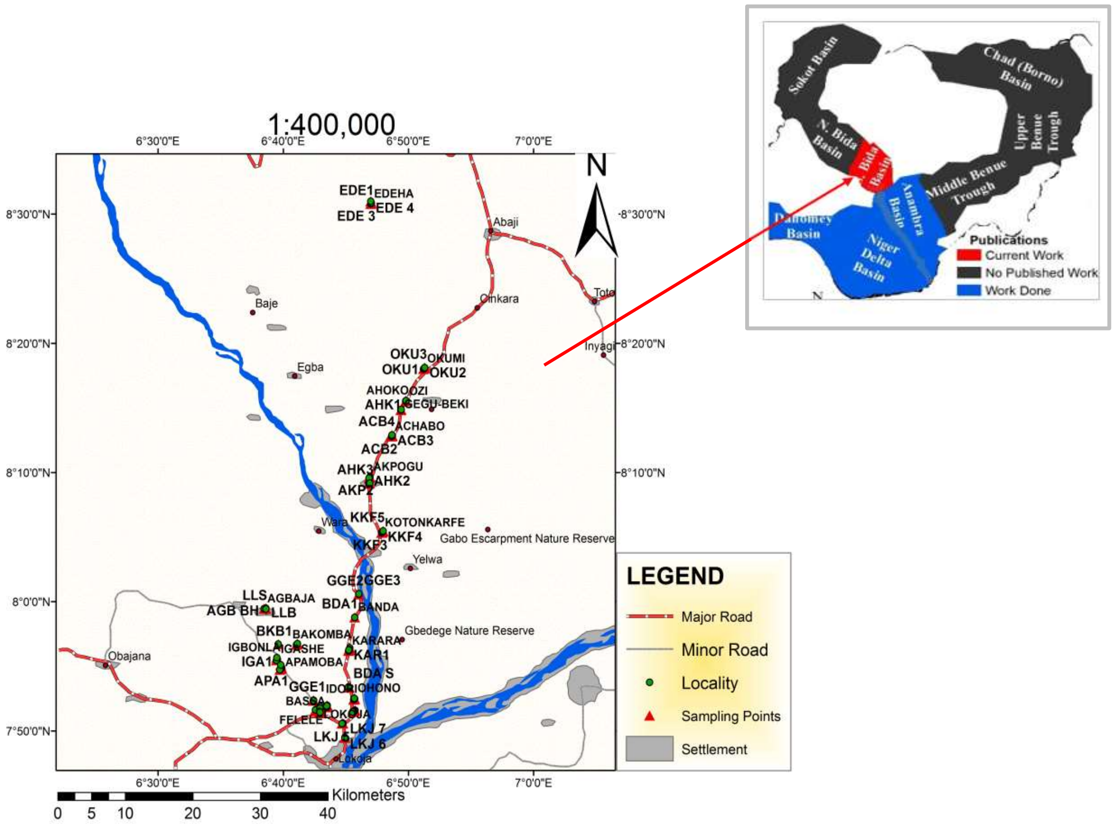

Figure 1: Location map of the study area showing sampling points.

Geology of the Study Area

The study area lies in the Mid-Niger or Nupe Basin. The Northern Bida Basin and Southern Bida Basin make up the Bida Basin's geological sequence (Adeleye, 1973). (Fig. 2). The Pre-Cambrian to Lower Palaeozoic Basement gneisses and schists are stratigraphically overlain by the Campanian to Maastrichtian Lokoja Formation in the Southern Bida Basin. The Maastrichtian Patti Formation covers it, and the Maastrichtian Agbaja Ironstone Formation follows (Ojo, 1992; Obaje, 2009).

The study was conducted in the Bida basin because of its intricately woven geological features, which are distinguished by sedimentary and basement formation. In addition, the research region is home to several communities that rely heavily on water for urbanization, agriculture, and other uses in response to population growth. Due to the rising demand for water and the resulting water stress on the existing water supply sources, it is crucial to analyse the precise physico-chemical characteristics of the basin's groundwater (Ige *et al.,* 2020).

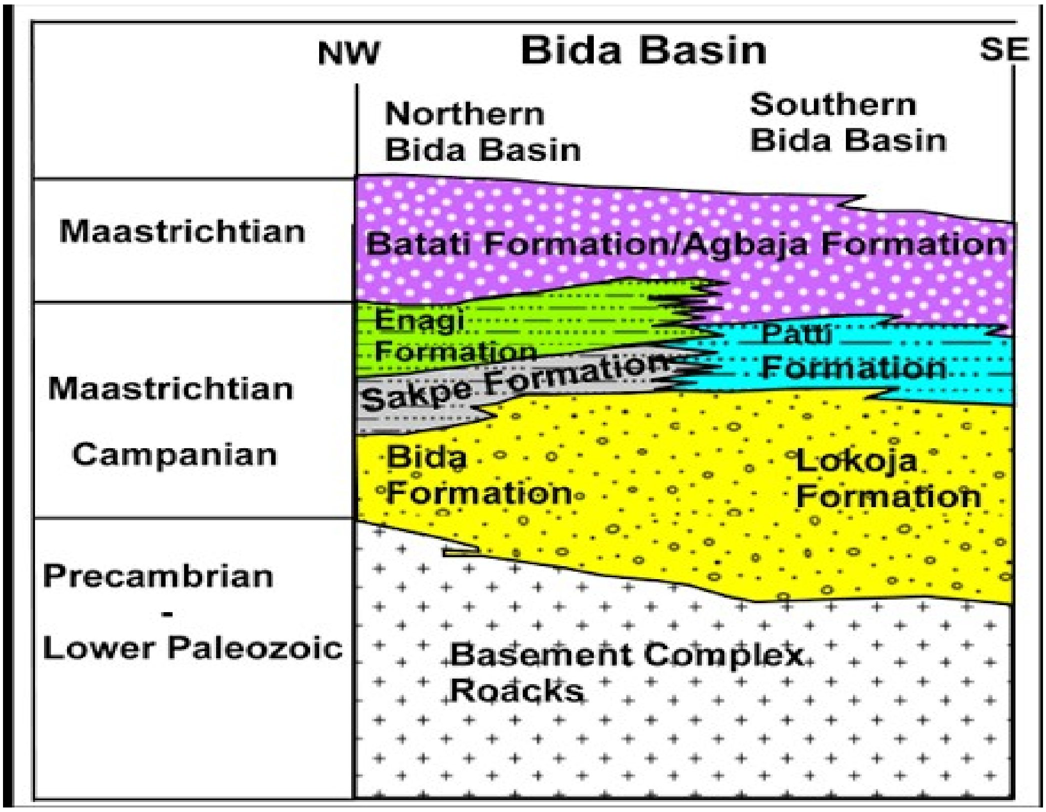

Figure 2: Stratigraphic succession of the Bida Basin (Akande, 2005)

MATERIALS AND METHODS

Across the whole study area, 83 samples of groundwater were randomly obtained from hand-dug wells and boreholes. Water samples were taken in plastic containers that had been thoroughly cleaned with distilled water and the water being analysed. Using a hand-held instrument, variables like pH, Total Dissolved Solids (TDS), temperature and electrical conductivity (EC) were assessed in-situ. The water samples were divided into those for the cations and anions tests, and the samples for the cations test were acidified with nitric acid and kept chilled. Within 48 hours after sampling, all water samples were delivered to the lab for analysis. All analyses were carried out using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to determine the concentration of the ions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} Cl^{-}, HCO_3^{-}, CO_3^{2-} and SO_4^{2-} in each water sample. Generally, the accepted procedure (APHA, 1995) was used for sample collection, preservation, and analysis.

RESULTS AND DISCUSSION

Results of physicochemical parameters

The findings of the statistical analysis of physicochemical properties of the water samples are presented as minimum, maximum, mean, and standard deviation (Table 1). pH values vary from 5.3 to 7.2 with a mean of 6.2 which indicates that the groundwater samples are slightly acidic to neutral. The values of EC vary from 10 to 1111.6 µS/cm with an average value of 344.8 µS/cm while TDS values vary from 10 to 634.3 mg/L with an average value of 179.6 mg/L. These TDS readings are suggestive of potentially potable water since they are classified as fresh water (Freeze and Cherry, 1979). The concentrations of calcium, magnesium, sodium, and potassium ranged from 0.9–70.0 mg/l, 1.4–155.0 mg/L, 0.6–170.4 mg/L and 0.3–301.5.05 mg/L with mean values of 22.2, 35.0, 31.2 and 30.0 mg/L, respectively. The concentration bicarbonate, chloride, sulphate, and carbonate ranged from 10.5–185.9 mg/L, 0.2–277.9 mg/L, 0.1–36.00 mg/L and 0.00-230.4 mg/L with mean values of 84.8, 44.0, 27.5 and 31.6 mg/L, respectively. All these values fall within the WHO and SON permissible limits except for pH and chloride in some samples which could be because of anthropogenic activities in the area.

Hydrochemical Facies Classification

The samples of groundwater from the study location were hydrochemically characterized using the primary ions; Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} Cl^{-}, HCO_3^{-} and SO_4^{2-}. According to the Piper's diagram (Fig. 3), the $CaHCO_3$ water type, which makes up around 70% of the research region, is the most prevalent groundwater facies, followed by mixed type (12%), NaCl type (10%), and CaCl type (8%).

Table 1: Summary of the statistics of analysed water samples.

Parameter	Mean	Std. Dev.	Min	Max
pH	6.2	6.6	4.7	7.2
EC (µS/cm)	344.8	322.7	10	1111.6
TDS (mg/L)	179.6	163.4	0	634.3
Total Alkalinity (mg/L)	81.5	55.4	8	184
Na (mg/L)	31.2	40.9	0.6	170.4
K (mg/L)	30	47.3	0.3	301.5
Mg (mg/L)	35	32.7	1.4	155
Ca (mg/L)	22.2	17.1	0.9	70
HCO_3 (mg/L)	84.8	55.7	11	185.9
SO_4 (mg/L)	27.5	67.4	0	256
CO_3 (mg/L)	31.6	58.4	0	230.4
Cl (mg/L)	44	71.1	0.2	277.9

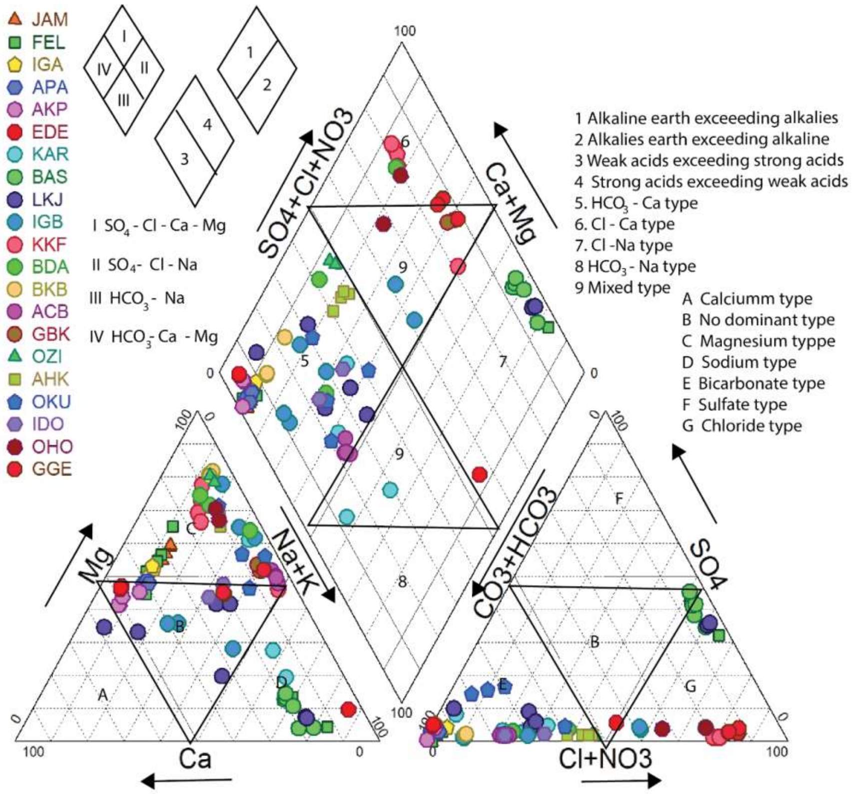

Figure 3: Piper’s diagram showing the positions of water samples.

Mechanisms Controlling Groundwater Geochemistry

Gibbs diagram

Many processes, which include precipitation, rock weathering, and evaporation process, can influence the chemistry of groundwater. Gibbs diagrams are frequently used to identify the key factors driving the chemical composition of water (Gibbs, 1970; Freeze and Cherry, 1979; Marandi and Shand, 2018). The Gibbs diagram's central portion was occupied by around 90% of the samples, indicating that water-rock interaction is the primary factor determining the chemical composition of groundwater (Figure 4).

End-member diagrams

End-member diagrams, as proposed by Gaillardet *et al*. (1999), are used to determine the makeup of the different types of rocks that are involved in the rock-water interactions that the Gibbs diagram identified as the primary process regulating water Hydrogeochemistry. By plotting Ca^{2+}/Na^{+} against ratios of Mg^{2+}/Na^{+} and HCO_3^{-}/Na^{+}, the End-member diagrams are created. Groundwater samples from the southern Bida basin were studied, and the end member diagram (Fig. 5) of those samples reveals that silicate weathering is the main hydrogeochemical process determining the chemical composition of groundwater.

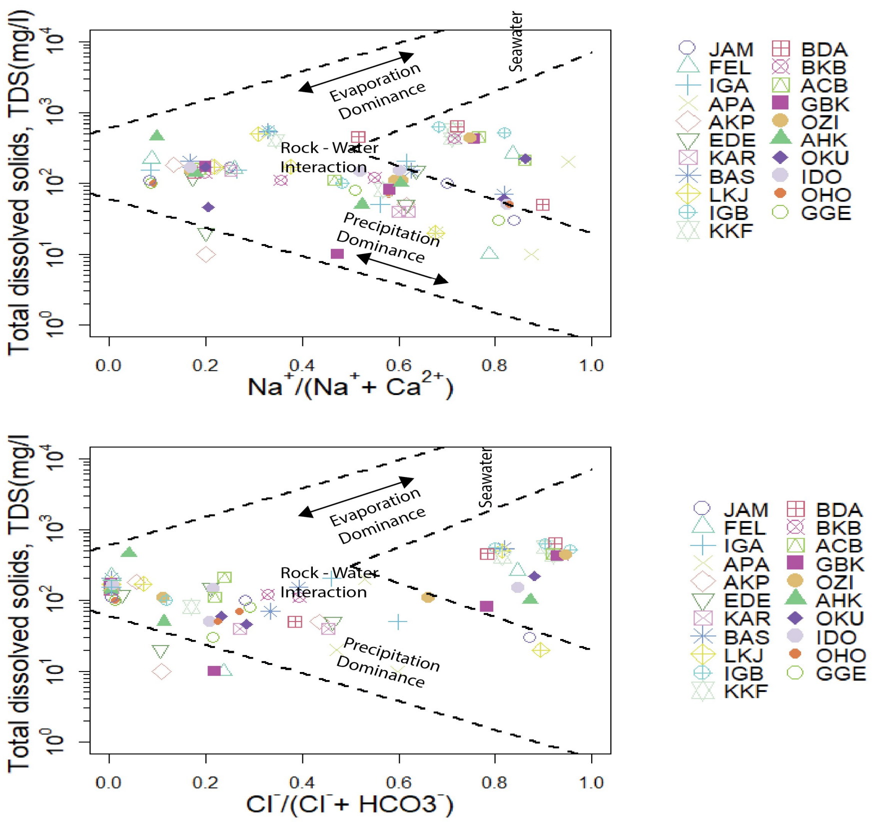

Figure 4: Gibb's diagram

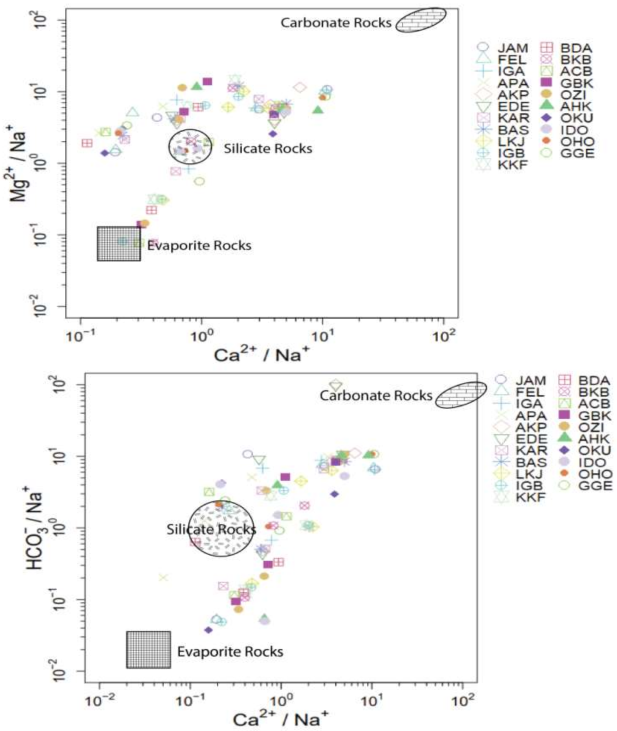

Figure 5: End member diagram

Ion exchange processes

Schoeller (1977) proposed the chloro-alkaline indices, CAI-1, and CAI-2, which are calculated using the formulae below, to comprehend the chemical exchange of ions between groundwater and its surrounding aquifer material during residency or travel. These indices' values might be either positive or negative. A direct cation exchange reaction occurs when Mg^{2+} and Ca^{2+} from the rocks are exchanged for Na^{+} and K^{+} from the groundwater (positive values of CAI-1 and CAI-2), whereas a reverse cation exchange reaction occurs when Mg^{2+} and Ca^{2+} from the rocks are exchanged for Na^{+} and K^{+} from the groundwater (negative values of CAI-1 and CAI-2) (Al-Ahmadi, 2013). For the groundwater samples in the research area, the chloro alkaline indices (CAI-1 and CAI-2) vary from -9.7 to 1.19 (mean = -0.91) and -16.7 to 2.15 (mean=-1.31), respectively indicating that the majority of the samples—roughly 90%—are undergoing reverse cation exchange reactions, in which Ca^{2+} and Mg^{2+} from the groundwater are interchanged for K^{+} and Na^{+} from the aquifer's material.

Chloro Alkaline Index 1,
$$CAI-1=\frac{Cl^{-}-(Na^{+}+K^{+})}{Cl^{-}}$$

Chloro Alkaline Index 2,
$$CAI-2=\frac{Cl^{-}-(Na^{+}+K^{+})}{SO_4^{2-}+HCO_3^{-}+CO_3^{2-}+NO_3^{-}}$$

Water Quality Evaluation for Irrigation

It is crucial to keep in mind that water deemed good for drinking does not necessarily meet the requirements for irrigation (Haritash *et al*., 2016). Water quality for irrigation suffers due to dissolved salt concentration (represented by dry residue/EC and Na+ concentration). The soil's permeability is decreased by too much sodium in irrigation water, and clay deflocculation, which affects soil structure. The following criteria were used to gauge the water quality for irrigational purposes.

Sodium Adsorption Ratio (SAR)

Based on SAR, Richard (1954) suggested a classification of irrigation-suitable groundwater. The sodium adsorption ratio (SAR), which measures the salt hazard in irrigation water, is the relative content of sodium, magnesium, and calcium in water. The availability of water for crops is subsequently lowered when there is an excess of sodium in groundwater, which decreases soil permeability. Based on SAR, water for irrigation is rated as excellent (S1), good (S2), doubtful (S3), and unsuitable (S4) for values of 10, 10-18, 18-26, and >26, respectively. SAR values range from 0.1 - 7.0 meq/l, with a typical value of 1.0 meq/l. In the research area, all groundwater samples are in the excellent category for irrigation usage according to the classification based on SAR (Table 2). The groundwater samples were from the S1 and C1–C3 fields, indicating a low sodium hazard and salinity that ranges between low and high, according to the salinity diagram (Fig. 6) proposed by the United States Salinity Laboratory (USSL, 1954). In C3-S1, which is typical of samples from Bassa and Felele, it is possible to cultivate plants with high and moderate salt tolerance, such as cotton and wheat.

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

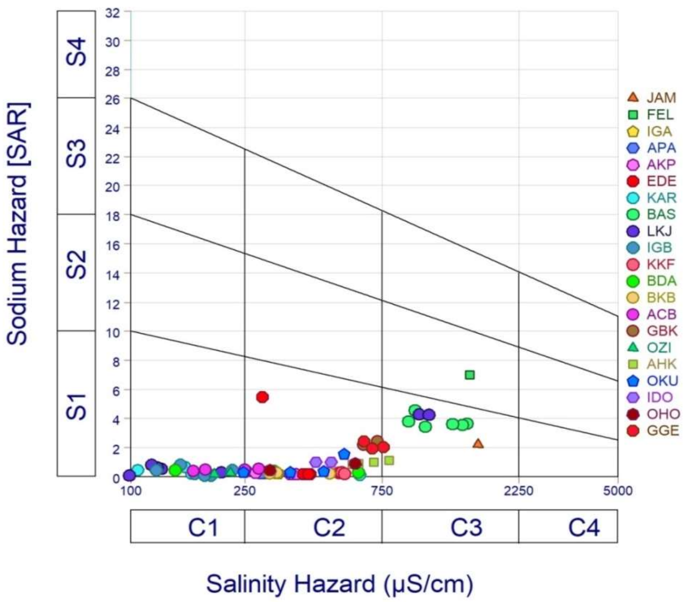

Figure 6: Salinity Diagram

Sodium Percent (%Na) and Soluble Sodium Percentage (SSP)

The sodium percent (% Na) or soluble sodium percent is a parameter that can be used to determine the impact of sodium content in groundwater for irrigational use (SSP). The classification of irrigation water takes sodium content into consideration since sodium interacts with the soil to reduce its permeability (Wilcox, 1955). For values of <20, 20-40, 40-60, 60-80, and >80, respectively, the sodium percent classification of water is excellent, good, permissible, doubtful, and unsuitable. According to this study's findings, the percent Na ranges from 4.4 to 84.7% (Mean = 23.0%); as a result, 61% are excellent, 24.4% are good, 6.1% are permissible, 7.3% are doubtful, and 1.2% are unsuitable for irrigational usage. For values under 60% and over 60%, respectively, the Soluble Sodium Percentage classifies water as suitable and unsuitable. Because the SSP of the groundwater samples ranges from 5.81 to 86.8% (Mean = 30.9%), 85% of the groundwater samples are deemed appropriate, and 15 percent are deemed unsuitable (Table 2).

$$\%Na = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+} \; x\, 100$$

$$SSP = \frac{(Na^+ + K^+)}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \; x\, 100$$

Wilcox plot

The groundwater samples from the study location are shown here as a plot of Na% against electrical conductivity (Wilcox, 1955). According to Fig. 7, 76% of the water samples fall into the excellent category, 23% fall into the doubtful and permissible category (mostly Bassa, Filele, and a few Lokoja samples), and the remaining 12% fall into the doubtful to unsuitable category because of their high sodium content. The excellent field's groundwater samples are ideal for irrigation since they do not allow soil aggregates to spread.

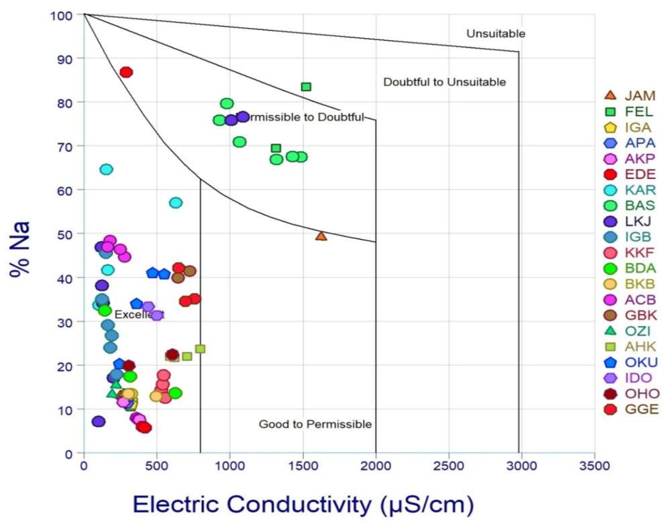

Figure 7: Wilcox Diagram

Kelley's Ratio

According to Kelly's ratio, Kelley (1951) discovered that the quality of irrigation water can be dangerously impacted by sodium. The formula below was used to determine Kelly's ratio, and all concentrations were represented in mg/l. With a mean value of 0.1, the KR values vary from 0.5 to 5.5. A value of >1 for Kelly's ratio denotes too much sodium in the water. Water with a Kelly's ratio below one is therefore good for irrigation, while water with a ratio beyond one is not. According to the current study's groundwater samples, 87% of them are suitable for irrigation, but 13% of them are not, which is typical of samples from Bassa and Edeha due to their high sodium concentration.

$$KR = \frac{Na^{+}}{Ca^{2+} + \ Mg^{2+}}$$

Permeability Index (PI)

The usage of irrigation water for an extended period and a rise in the soil's Na, Ca, Mg, and HCO3 levels can both have an impact on the permeability of the soils (Doneen, 1964). Using the equation below, the permeability index is determined. A classification of Class I (>75%), Class II (25–75%), and Class III (25%) irrigation water is possible based on the PI values. A permeability index value of more than 25% makes Class-I and Class-II water types appropriate for irrigation. The PI values of the research region are between 14.4 and 665%, with an average value of 73.9%. With PI exceeding 25% in nearly 87.8% of the groundwater samples, they can therefore be used for irrigation.

$$PI = \ 100 \ x \ \frac{Na^{+} + \sqrt{HCO3^{-}}}{Ca^{2+} + \ Mg^{2+} + \ Na^{+}}$$

Suitability of the groundwater sources for drinking purposes and possible health impacts

For long-term groundwater users, the World Health Organization (WHO, 2011) and the Standard Organization of Nigeria (SON, 2007) recommendations were utilized to assess the water quality and potential effects on the health of humans (Table 3). It demonstrates that, based on their physico-chemical characteristics, most groundwater samples from the study location are suitable for domestic use because they are within permissible limits; however, a small number of samples, particularly those from Bassa and Felele, have chloride concentrations that are higher than the maximum permissible limits, this may be due to anthropogenic and geogenic activities and this may pose a health risk. Considering this, a map of water quality was created to show regions where groundwater is potable, at risk of contamination, and mildly contaminated based on WHO approved standards (Figure 8).

Table 2: Summary of irrigation parameters

Parameter	Range	Water Class	% Samples
Sodium Absorption Ratio	0 -10	Excellent	100
	11 – 17	Good	-
	18 – 26	Doubtful	-
	>26	Unsuitable	-
Soluble Sodium Percentage	<60%	Suitable	85
	>60%	Unsuitable	15
Wilcox plot	<750	Excellent	84
	750 – 2250	Permissible	16
	>2250	Unsuitable	-
Kelley's ratio	<1	Suitable	87
	>1	Unsuitable	13
Permeability Index	>75	Suitable (class I)	30
	25 – 75	Suitable (class II)	58
	<25	Unsuitable (class III)	12

Table 3: Comparison of samples with drinking water guidelines

Parameters	Range (this research)		WHO (2011) Permissible and maximum limit		SON (2007)	Health implications/ Side effects
	Min	Max				
pH	4.7	7.2	6.5	8.5	6.5-8.5	Pipe corrosion, impaired taste
EC (µS/cm)	10	1111.6	900	1250	1000	Salty taste
TDS (mg/L)	10	634.3	<600	1000	1000	Salty taste, pipe scaling
TA (mg/L)	8	184	-	-		
Na (mg/L)	0.6	170.4	200	300	200	High blood pressure
K (mg/L)	0.3	301.5	-	-		
Mg (mg/L)	1.4	155	60	170		Hardness/ gastro-intestinal irritation
Ca (mg/L)	0.9	70	100	500	75	Furring of kettle, wastes soap
HCO_3 (mg/L)	10.5	185.9	550	1000	1000	Seizures, heart failure
SO_4 (mg/L)	0	256	250	1000	100	Laxative effect
CO_3 (mg/L)	0	230.4	-	120	-	
Cl (mg/L)	0.2	277.9	250	250	100	Salty taste

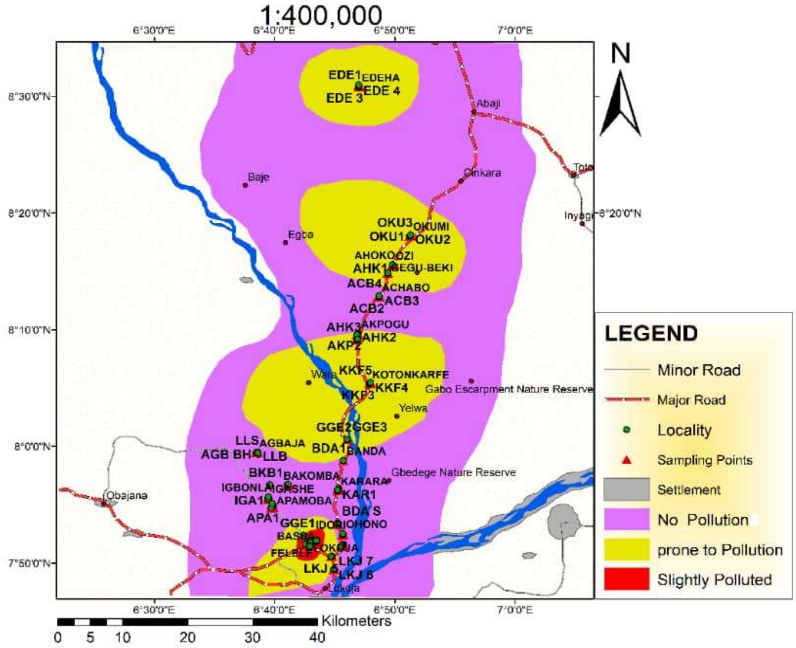

Figure 8: Water quality map

Geochemical Modeling

Geochemical models are used to calculate chemical reactions in groundwater systems such the dissolution and precipitation of solids, ion exchange, and sorption by clay minerals (Plummer, 1984). The Saturation Index (SI) indicates whether water would typically precipitate or dissolve a specific material. When the value is negative, the groundwater is under-saturated with respect to that specific mineral and the mineral may be dissolved. When the value is positive, the groundwater is saturated with respect to the mineral and is unable to dissolve any more of the mineral, which causes it to precipitate. When the value is zero, the water and mineral are at chemical equilibrium (Plummer, 1984).

The ion activity product (IAP), which measures the chemical activities of the mineral's dissolved ions, is used to determine SI (Ksp). In this research, SI calculations were made using PHREEQC software.

$$SI = \log(\frac{\mathrm{IAP}}{\mathrm{K_{sp}}})$$

Table 4 provides an overview of the data on the mineral saturation index (SI) for selected minerals for groundwater samples. Calcite, aragonite, dolomite, gypsum, and anhydrite all have SI values that are negative, indicating unsaturation, which is typical of silicate-hosted groundwater aquifers.

Table 4: Summary Statistics of saturation indices with respect to certain mineral species

	Mean	Min	Max
Calcite	-1.46	-3.06	-0.47
Aragonite	-1.61	-3.21	-0.61
Dolomite	-2.38	-4.76	-0.82
Gypsum	-3.44	-5.16	-1.28
Anhydrite	-3.66	-5.38	-1.50

Statistical Evaluation

Pearson Correlation

Table 5 displays the matrix of Pearson correlation coefficients for the parameters of the water samples that were tested and analysed. In this study, correlation coefficients larger than 0.6 are regarded as strong, and correlation coefficients less than 0.6 as low. Due to their natural relationship and the fact that one can theoretically calculate the value of the other knowing the value of the first, TDS and EC have a high positive correlation (0.9). Na, K, SO_4, and Cl have correlation coefficients of 0.66, 0.63, 0.73, and 0.85 with TDS, indicating that these key ions are the main sources of the measurement of Total Dissolved Solids (TDS) in the samples. Additionally, there is a strong positive correlation between sodium and each of the following: sodium and K (0.68), sodium and SO_4 (0.68), and sodium and Cl (0.82). In the crystal lattice of common minerals, the cations Na and K can interchange since they are linked.

Factor Analysis

Utilizing the statistical approach of factor analysis, one can reduce the number of variables in a dataset by discovering the latent relational structure among the variables. After factor analysis, the best number of factors is chosen using techniques like parallel analysis and eigenvalue. Three components emerged from the investigation, accounting for 70% of the overall variance. Factor 1, which has high positive loadings on EC, TDS, and Cl, moderate positive loadings on pH, Na, K, and Ca, and negative loadings on CO3, explains 41% of the total variance. The relationship between these chemical elements, which can be referred to as "the water-rock interaction factor," represents the impact of water-rock interaction on groundwater quality. Factor 2, which accounts for 20% of the variance overall and has significant positive loadings for both total and HCO_3 levels, may be referred to as the alkaline factor. Alkalinity refers to the quantity of ions in water that are present and neutralize hydrogen ions. The three substances that make up most alkalinity are bicarbonate, carbonate, and hydroxide. Because most of the groundwater samples have greater magnesium concentrations than calcium, factor 3, which accounts for 9% of the overall variance, has strong positive loadings on Mg.

Table 5: Pearson correlation coefficient matrix of the measured and analysed parameters

	pH	EC	TDS	TA	Na	K	Mg	Ca	HCO_3	SO_4	CO_3	Cl
pH	1											
EC	0	1										
TDS	0	0.91	1									
TA	-0.1	-0.3	-0.3	1								
Na	-0	0.63	0.66	-0.5	1							
K	-0	0.6	0.63	-0.3	0.68	1						
Mg	0.02	0.15	0.13	-0.2	0.29	0.24	1					
Ca	-0	0.36	0.43	0.19	0.33	0.2	0.23	1				
HCO_3	-0.1	-0.3	-0.3	1	-0.5	-0.3	-0.2	0.17	1			
SO_4	-0	0.63	0.73	-0.3	0.68	0.55	-0.3	0.3	-0.32	1		
CO_3	-0.1	-0.4	-0.4	0.09	-0.2	-0.2	0	-0.5	0.09	-0.2	1	
Cl	0	0.78	0.85	-0.5	0.82	0.68	-0	0.27	-0.49	0.92	-0.2	1

CONCLUSIONS

Aspect of geochemical and water quality studies of Southern Bida groundwater samples have been evaluated. The discussion covered the principal ion concentrations, the origin of the dissolved ions, the hydrochemical facies, variables affecting the chemistry of groundwater, the geochemical processes in the groundwater, the ion exchange mechanisms, and the suitability of the waters for irrigation and drinking. Except for a few samples that slightly exceed the recommended values, most notably chloride values, which can be attributed to anthropogenic activities of the residents in residential areas and can affect water taste, ion concentrations are generally within acceptable limits advised by relevant standards such as WHO and SON. In terms of cation and anions, the order of ionic dominance is $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-}$ respectively. The hydrochemical facies are classified into $CaHCO_3$ (70%) > mixed CaMgCl and $CaNaHCO_3$ (12%) > NaCl (10%) > CaCl (7%). Except for a small percentage (15%) of samples that have excess sodium concentration, which can reduce soil permeability, irrigation parameters indicate that most of the samples are fit for irrigation. The largest ion contributors to the ions in the water samples were shown by several ionic plots to be silicate weathering. The main process affecting the chemistry and quality of groundwater is the interaction between water and rock; other processes include weathering of the host rock through mineral dissolution, silicate weathering, and inverse cation exchange reactions. The chloro-alkaline indices showed that nearly all samples (90%) were experiencing reverse cation exchange reactions, in which Ca^{2+} and Mg^{2+} from the groundwater are swapped out for K^{+} and Na^{+} from the aquifer's material. According to geochemical modeling, all water samples are undersaturated relative to the environment, which causes the minerals to dissolve and is typical of silicate-hosted groundwater aquifers. A high correlation coefficient between particular ions and TDS suggests that these significant ions are the main sources of the measurement of Total Dissolved Solids (TDS) in the samples. Most of the water samples from the southern Bida basin are fresh water sources, according to the TDS readings, making them fairly suitable for drinking. As a result, the water sources are moderately to adequately appropriate for drinking and agriculture. It is therefore recommended that further research should be carried out on the trace elements present in the water samples to further provide information on the groundwater quality.

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